STUDENT ID NO

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MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2018/2019

ENT2016 – SOLID STATE ELECTRONICS
(Nano)

01 MARCH 2019
15.00 – 17.00
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 6 pages with 4 Questions only.

2. Attempt all **FOUR** questions. The distribution of the marks for each question is given.

3. Please print all your answers in the Answer Booklet provided.

Question 1

(a) With the aid of a diagram, illustrate and compare different types of solids.

[3 marks]

(b) Explain the difference between a primitive cell and a unit cell. What are the functions of both concepts?

[3 marks]

(c) Illustrate (hlk) ≡ (643) and (hlk) ≡ (212) planes.

[3 marks]

(d) Consider Molybdenum (Mo) is a body centered cubic (BCC) unit cell. If Mo consists of a mono-atomic crystal structure, then answer the following. Consider, Mo has an atomic density of the unit cell equivalent to 1.6×10^{22} cm^{-3},

   (i)   Sketch the BCC unit cell with mono-atomic basis.   [2 marks]

   (ii)   Calculate the lattice constant.   [3 marks]

   (iii) Calculate is the atomic density per unit area on the (110) plane.   [3 marks]

   (iv)   Find the nearest neighbor atomic distance for this cell.   [2 marks]

   (v)   Determine the radius of each atom.   [1 marks]

(e) Calculate the volume density of Si atom (number/cm^3), given that the lattice constant of Si is 5.43Å. Calculate the areal density of atoms (number/cm^2) on the (100) plane.

[5 marks]

Continued...

Question 2

(a)   Briefly explain the reason why in a crystal structure forming a point defect is energetically more favorable than forming a dislocation?

[2 marks]

(b)   All substances have real surfaces. When the crystal lattice is abruptly terminated by a surface, the atoms at the surface cannot fulfill their bonding requirements (Figure Q.2b). Explain the bonds that may form in the abruptly terminated crystal surfaces.
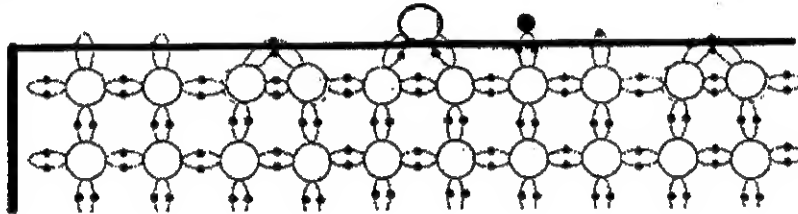

Figure Q.2b   [4 marks]

(c)   The potential energy E per Na^+-Cl^- pair crystal on the interionic separation r can be defined by:

$$E(r) = -\frac{e^2 M}{4\pi\varepsilon_o r} + \frac{B}{r^m}$$

Where, for NaCl,

$M = 1.763$, $B = 1.192 \times 10^{-104}$ J m^9 or 7.442×10^{-5} eV (nm)^9 and $m = 9$.

     (i)   For NaCl, find the equilibrium separation (r_o) of the ions in the crystal.

[5 marks]

     (ii)   Find the ionic bonding energy, that is, the ionic cohesive energy. Compare the ionic bonding energy value to the experimental value of 657 kJ mol^{-1}. Given the ionization energy of Na is 3.89 eV and the electron affinity of Cl (energy released when an electron is added) is 3.61 eV.

[7 marks]

     (iii)   Calculate the atomic cohesive energy of the NaCl crystal in joules per mole.

[3 marks]

(d)   A Si crystal has been doped with Phosphorous (P). The donor concentration is 10^{15} cm^{-3}. Find the conductivity and resistivity of the crystal.

[4 marks]

Continued...

Question 3

(a)   Thomas Young performed his famous double slit experiment which seemed to prove that light was a wave. Based on Young's Double-Slit Experiment on light explain how constructive and destructive interference can occur.

[5 marks]

(b)   Cesium (Cs) metal is to be used as the photocathode material in a photoemissive electron tube because electrons are relatively easier to be removed from a cesium surface. The work function of a clean cesium surface is 1.9 eV.

(i) What is the longest wavelength of radiation which can result in photoemission?

[3 marks]

(ii) If blue radiation of wavelength 450 nm is incident onto the Cs photocathode, what will be the kinetic energy of the photo emitted electrons in eV? What is the voltage required on the opposite electrode to extinguish the external photocurrent?

[6 marks]

(c)   Classical physics cannot explain **THREE** (3) of the main results of photoelectric-effect experiment as shown in the Figure Q3(c). What are these three experiment results? Use diagram to support your answers.
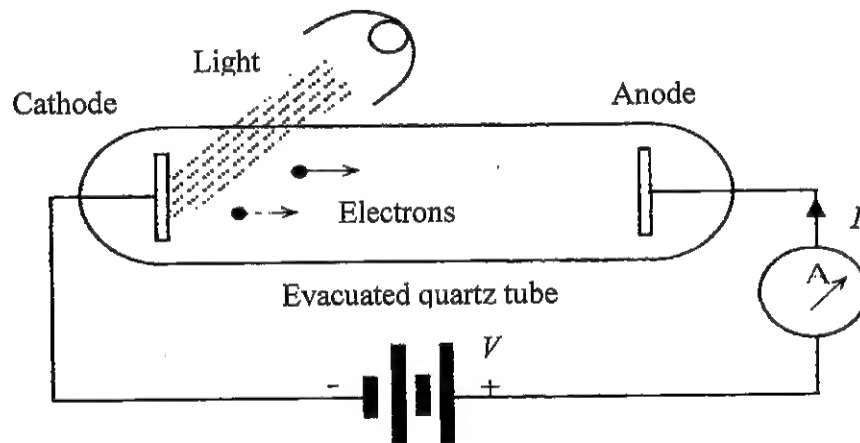

Figure Q3(c)

[6 marks]

(d)   Consider a free electron having energy level as E. For a particular position what is the uncertainty of finding an electron and how it is related with the uncertainty in the momentum of the electron?

[5 marks]

Continued...

Question 4

(a) Briefly describe the following:
     (i)   Mean free path   [2 marks]
     (ii)   Intrinsic Semiconductor   [2 marks]
     (ii)   Extrinsic Semiconductor   [1 mark]
     (iii)   Matthiessen's Rule   [1 mark]
     (iv)   Kronig-Penney Model   [2 marks]

(b) Given that the electron effective mass m_e^* for the GaAs is $0.067m_e$, calculate the thermal velocity of the conduction band (CB) electrons. The electron drift mobility μ_e depends on the mean free time τ_e between electron scattering events (between electrons and lattice vibrations). Given $\mu_e = e\tau_e / m_e^*$ and μ_e=8500 cm2 V-1 s-1 for GaAs, calculate τ_e, and hence the mean free path $\ell = \tau_e v_{th}$ of CB electrons.

[5 marks]

(d) Calculate the probability that a state in the conduction band is occupied by an electron at $T = 300K$. Assume that the Fermi energy is 0.57 eV below the conduction band and the bandgap energy of GaAs is 1.42 eV.

[4 marks]

(e) A Si wafer has been doped n-type with 10^{17} As atoms cm^{-3}.

     (i)   Given that the drift mobility $\mu_e \approx 800$ $cm^2V^{-1}s^{-1}$, calculate the conductivity of the sample at 27° C. Where is the position of Fermi level in this sample at 27° C with respect to the Fermi level (E_{Fi}) in intrinsic Si?

[3 marks]

     (ii)   The n-type Si sample above is further doped with 9×10^{16} boron atoms (p-type dopant) per cm^{-3}. Calculate the conductivity of the sample at 27 °C. Where is the Fermi level in this sample with respect to E_{Fi} at 27 °C? Is this an n-type or p-type Si? (Note: The mobility due to boron doping changes to 700 cm^2 V^{-1} s^{-1}).

[5 marks]

Continued...

Useful constants and materials properties:

Physical constants		
Boltzmann's constant	k	1.3807×10^{-23} JK^{-1} 8.617×10^{-5} eVK^{-1}
Planck's constant	h	6.626×10^{-34} J s
Thermal voltage @ 300 K	kT/e kT	0.0259 V 0.0259 eV
Electron mass in free space	m_e	9.10939×10^{-31} kg
Electron charge	e	1.60218×10^{-19} C
Effective density of states in the conduction band (for Si)	N_c	2.8×10^{19} cm^{-3}
Effective density of states in the Valence band (for Si)	N_v	1.04×10^{19} cm^{-3}
Permeability of free space	μ_o	$4\pi \times 10^{-7}$ H/m
Permittivity of free space	ε_o	8.85×10^{-12} F/m
Avogadro's number	N_A	6.023×10^{23} mol^{-1}

Semiconductor Materials Properties at 300 k					
Materials	Energy gap	Intrinsic concentration	Electron mobility	Hole mobility	Dielectric Constant
Notations	E_g (eV)	n_i (cm^{-3})	μ_e (cm^{2}V^{-1}s^{-1})	μ_h (cm^{2}V^{-1}s^{-1})	ε_r
Si	1.10	1×10^{10}	1350	450	11.7
GaAs	1.42	2.1×10^{6}	8500	400	13.1
Ge	0.66	2.3×10^{13}	3900	1900	16

End of Paper